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ORIGINAL PAPER

Soil disturbances due to machinery traffic on steep skid trail in the north mountainous forest of Iran

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Abstract: A study was conducted to investigate the effects of skid trail slope and traffic levels on soil disturbances at two soil depths (0−10 and 10−20 cm). The treatments were set at four traffic levels (2, 7, 12 and 20), two slope classes (<20% and >20%) and two soil depths (0−10 and 10−20 cm). Results show that skidder traffic, longitudinal slope and soil depth have significant effect on soil bulk density in skid trail. Comparison of average soil bulk density in different traffic levels shows that there are significant differences in average bulk density between different traffic levels and control ($p<0.05$). The average bulk densities in different slopes and soil depths are significantly increased with increase in traffic levels, maximized at 12 passes ($p<0.05$), but there are no significant differences between 12 and 20 passes. The interaction effects between traffic and soil depth are significant ($F_{0.05,3}=0.109$, $p<0.001$). For all traffic treatments, there are significant differences in soil moisture content between the two slope classes and the two depths ($p<0.001$). However, the interaction effects between traffic levels and slope classes are not significant ($p>0.05$), although skidder traffic and slope affected soil moisture content.

Keywords: Iranian forest; porosity; skid trail slope; soil compaction; soil disturbances

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Introduction

There are more than one million hectares of industrial forest in northern Iran, which supply about 27% of the national wood product requirements (Naghdi et al. 2008). The mechanized system of extracting wood in northern forests of Iran is ground skidding system in which different types of skidders are used and the most common type used is 450C Timberjack wheel skidder, but in limited harvesting areas HSM wheeled skidders are also used.

Skidder traffic and transporting wood along forest floor can cause soil compaction, which results in decreased water infiltration, problems in soil aeration and inhibits root development; therefore forest regeneration is threatened (Trautner and Arvidsson 2003). Soil compaction, which is the first consequence of skidder traffic, is a process in which soil particles compact together because of forces acting on them (Rab et al. 2005).

Naghdi et al. (2007) in their research for two soil types (clay soil with high (CH) and low liquid limits, (CL)) using 450C Timberjack wheel skidder showed that the effect of skidder traffic on an increase in soil bulk density at sample locations was significant. The increment of soil bulk density in sample locations ranged from 15.8% to 62.6% compared to the control. Wiliamson and Neilsen (2000) in their study of soil compaction in skid trails during harvesting chose a plot of 20 m ×5 m for sampling. In each plot they randomly took two samples with cylinder from the left and right wheel tracks at 0−10, 10−20 and 20−30 cm soil depth. The rate and extent of soil compaction on skid trails was measured at six field locations covering a range of dry and wet forests. Data was collected for up to 21 passes of a laden logging machine. A similar extent of compaction, averaging 0.17 g/cm^3 increase in total soil bulk density, was recorded for all field sites despite substantial site and soil differences. Jansson and Johansson (1998) in their study on a silt loam in Sweden concluded that the wheeled machine caused a decrease in bulk density at 5 cm depth, whereas the tracked machine caused an

increase, despite its lower ground pressure. Siegel-Issem et al. (2005) confirmed that bulk density interacts with soil moisture content, at both the dry or wet end of the spectrum, to produce either high soil strength or poorly aerated conditions. The review by Håkansson and Reeder (1994) showed that the risk of subsoil compaction may be considerable for soils with high moisture content under vehicles with high axle loads.

The number of machine passes is a factor that significantly influences the degree of soil damage (Jun et al. 2004). Machine passes have an important influence on soil structural characteristics, soil aeration and the soil water balance, and may therefore considerably affect soil organisms and root development. The initial passes cause the highest increase in soil compaction in relation to subsequent passes but these may lead to further soil disturbance by deepening the ruts.

Naghdi et al. (2009) in their study on rutting and soil displacement caused by 450C Timberjack wheeled skidder on clay loam and sandy clay loam soils showed that there was a significant difference between the longitudinal slope increase of skid trail and the amount of soil volume displaced. However, there was no significant correlation between the mean rut depth and different classification of longitudinal slope along the skid trail.

In general, soil compaction increases dry bulk density and decreases infiltration rate and soil saturated hydraulic conductivity, which cause erosion potential in skid trail to increase. The aim of this research was to assess the effect of skid trail slope and traffic levels on soil disturbances in a northern forest of Iran. With respect to this, the parameters measured were soil bulk density and moisture content changes at four traffic levels (2, 7, 12 and 20), two slope classes (<20% and >20%) and two soil depths (0–10 and 10–20 cm) in three replication.

Materials and methods

Site description

This research was carried out in summer 2008 in compartment 41 of third district of Nav-Asalem forest, Guilan Province, northern Iran (Fig. 1). The area is located between 48°39'30"E and 48°44'30"E longitude, and 37°37'20" N and 37°61'12" N latitude, with an altitude ranging from 1 550 to 1 800 m above sea level, and receives an average annual precipitation of 1 100 mm.

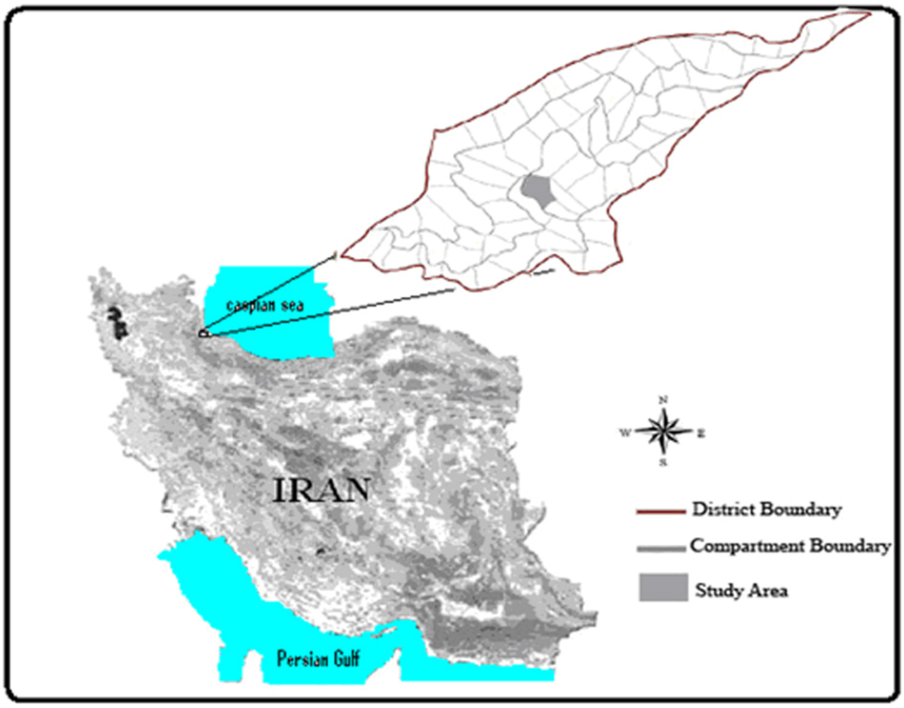

Fig. 1 Compartment 41 of third district of Nav-Asalem forest in northern Iran (study area)

The forest type with uneven-aged was fagetum (*Fagus orientalis* Lipsky). The area of the compartment was 62 ha, with a dominant slope of 10%–50% and North-West aspect. Single selection method was used in the study region. The logs with short and long shape were extracted from stump area to road side landing by a ground-based skidding system. The skidding direction along the skid trail was downslope. The parent material was calcelous, and the soil texture was coarse-loamy. The skidder type used in this study was 450C Timberjack cable skidder, with 130 kW and 10257 mass.

Experimental design and data collection

A skid trail of 680 m length with downslope skidding direction

was chosen for the experiments. In choosing the skid trail, attempts were made to select a trail that had different longitudinal slopes and no lateral slope. The longitudinal profile showed that the slopes of skid trail ranged from 0 to 36%. The factorial design was generalized to three factors and each factor was fixed. Four traffic levels (2, 7, 12 and 20), two slope classes (<20% and >20%) and two soil depths (0–10 and 10–20 cm) were applied in three replication (Jansson and Johansson 1998; Laflen et al. 1991). In total, 48 plots (12 m ×5 m in size for each) were set up in the study.

In order to measure bulk density and soil moisture content, we took soil samples in each plot along five randomized lines across the wheel track perpendicular to the direction of travel with a 2-m buffer zone between lines to avoid interactions. Then three lines were randomly chosen and at three different points of each line (left wheel track, right wheel track and log track or between tracks) and from the forest floor (control) one sample was taken (Fig. 2).

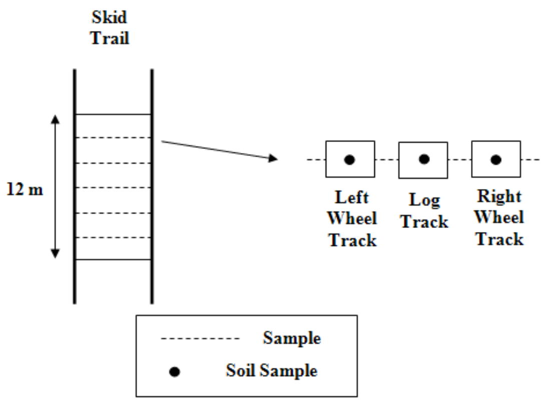

Fig. 2 Sketch of the treatment set-up with the location of the sample lines within the plots

Soil bulk density was determined by cylindrical method with 10 cm height and 5.5 cm diameter. Soil samples were placed in polyethylene bags and transferred to lab and wet weights of soil samples were measured instantaneously. Then the samples were dried in oven at 105°C (24 h) and weighed again. Soil bulk density and percentage of soil moisture content were determined by use of the formula below:

$$SDBD = W_d / Cv$$

where *SDBD* is the soil dry bulk density (g·cm^{-3}), W_d is the weight of the dry soil (g), and *Cv* is the volume of cylinder (cm^3).

$$SMC = \frac{W_w - W_d}{W_d}$$

where *SMC* is the soil moisture content (%), W_w is the weight of wet soil (g), and W_d is the weight of the dry soil (g).

Statistical analysis

One-way and three-way ANOVA by SPSS software version 9.01 was used to assess the significant differences between average bulk density in different traffic levels, positions, and depths and their interaction effects. Because of unequal variances, Dunnett's T3 test was used to determine the significant differences between average bulk density of control in different traffic, positions, and depths. Levene test was used for testing equality of variances.

Results and discussion

Soil bulk density

The results showed that skidder traffic, longitudinal slope, and soil depth had significant effect on soil bulk density in skid trail. With regards to variances being unequal, the results from comparison of average soil bulk density in different traffic levels with the use of Dunnett's T3 test showed that there were significant differences in average bulk density between different traffic levels and control (p<0.05). The results reported by other researchers showed that soil bulk density increased by increase in traffic levels (Startsev and McNabb 2001; Fernandez 2002; Carter and Shaw 2002; Buckley et al. 2003; Raper 2005; Chan et al. 2006; Makineci et al. 2007; Demir et al. 2007;).

The average bulk density in different positions were significantly different (p<0.001). The amount of bulk density between left track and right track was not significantly different (p>0.05) and this can be attributed to no lateral slope in skid trail. Gantzer et al. (2006) showed that bulk density in wheel tracks was significantly increased compared to control at 0–30 cm depth

Table 1. One-way ANOVA showing relationship between average bulk density and slope classes and soil depths

Variation sources	Sum of square	df	Mean of square	F	p-value
Between groups	4.202	2	0.03	9.36	<0.05
Within groups	3.639	143	0.281		
Total	0.563	141			

With increase in traffic levels, average bulk density in different slopes and soil depths was significantly increased (Table 1). This increase was maximized at 12 passes, but there were no significant difference between 12 and 20 passes (Figs. 3 and 4). Since no sampling was taken between 7 and 12 passes, it can be said that maximum bulk density occurred between 7 and 12 passes. Buckley et al. (2003) stated that amount of soil compaction was related to intensity of traffic, soil type and soil moisture content in skidding time. Startsev and McNabb (2000) confirmed that at high soil moisture content, maximum soil bulk density occurred after three passes, while at low moisture content, maximum soil bulk density occurred after 12 passes. Their results are in accordance with the results of the present study. Our study was conducted in dry season. The average soil moisture content at 0–10 cm depth during skidding operation was 23%

and maximum soil bulk density occurred at 12 passes.

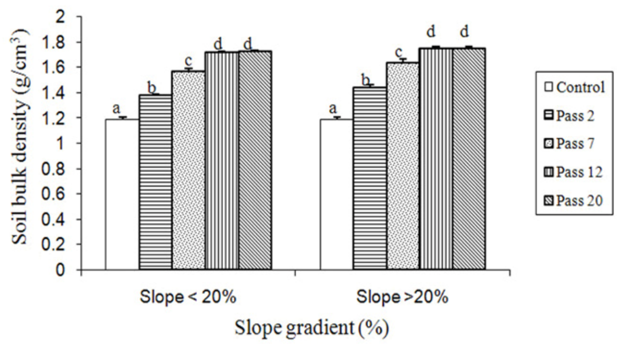

Fig. 3 Effect of traffic levels on soil bulk density at soil depth of 0–10 cm. Different letters in the columns show significant differences (p<0.05).

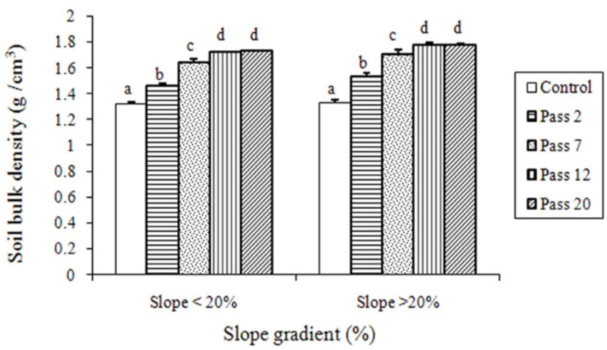

Fig. 4 Effect of traffic levels on soil bulk density at soil depth of 10–20 cm. Different letters in the columns show significant differences (p<0.05).

Moisture content causes soil particles to compress together easier due to force acting upon the soil. Therefore, soil bulk density increases with more intensity or soil porosity decreases with more intensity (Mosadeghi et al. 2000). Botta et al. (2006) showed that dry bulk density significantly increased at 10 and 12 passes with increase in soil moisture content.

The results of GLM Univariate show that compared to control, the bulk density increase at different traffic levels were significantly different between the two soil depths (0–10 and 10–20 cm) ($F_{0.05,1}$=3.925, p<0.001) and between two slope classes ($F_{0.05,1}$=23.695, p<0.001). Also, the bulk density increase among different traffic levels (except 12 and 20 passes), at two depths (0–10 and 10–20 cm) and two slope classes were significantly different (p<0.05). The average bulk density at slope of >20% was higher than slope of <20%, but there was no significant interaction effects between traffic and slopes (p>0.05). The interaction effect between slope, depth and traffic were significant ($F_{0.05,3}$=0.232, p<0.005).The interaction effects between traffic and soil depth were significant ($F_{0.05,3}$=0.109, p<0.001). The average bulk density percentage increase compared to control in both slope classes was higher in first depth than second depth (Figs. 5 and 6).

The reason for increase of soil compaction in steep slope of skid trails was due to decrease in skidder speed. With decrease in skidder speed, the soil was compacted longer, so that compaction intensifies. Longitudinal slope of skid trail causes the occurrence of the maximum soil compaction or minimum soil porosity at lower skidder traffic. Therefore, maximum bulk density occurred at 12 passes, slope <20% and 7 passes, slope >20%. Rab et al. (2005) reported that during skidding the soil disturbances increased in both extent and depth with increasing slope.

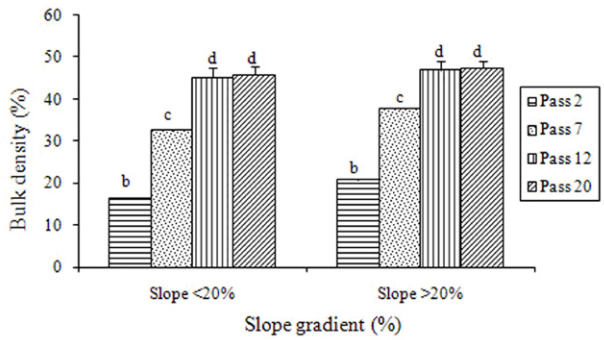

Fig. 5 Effect of traffic levels on soil bulk density increase at soil depth of 0–10 cm

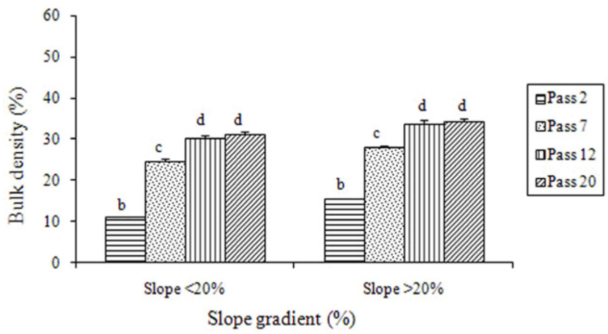

Fig. 6 Effect of traffic levels on soil bulk density increase at soil depth of 10–20 cm

Soil moisture content

Soil moisture content at depths of 0–10 and 10–20 cm were decreased from 31% and 36% at undisturbed area (control) to 19.05% and 27.5% at treatment with slope >20% and 20 passes, respectively. For all traffic treatments there were significant differences between soil moisture content at two slope classes and two depths (p<0.001).

For each slope and depth, soil moisture content was decreased in skid trail with regards to traffic levels (Figs. 7 and 8). The highest soil moisture content was 34.4% at second depth at treatment with slope >20% and 2 passes and the lowest was 19% at first depth at treatment with slope >20% and 20 passes. Although skidder traffic and slope affected soil moisture content, but the interaction effect between traffic levels and slope classes

were not significant (p>0.05).

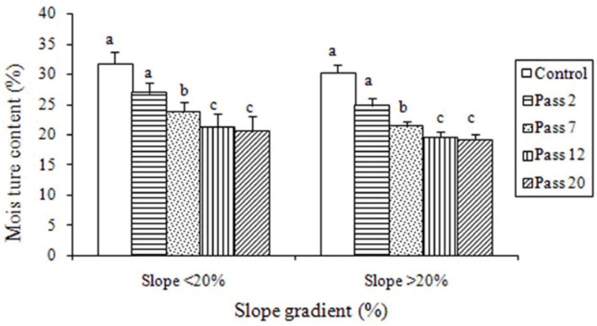

Fig. 7 Effect of traffic levels on soil moisture content at soil depth of 0–10 cm

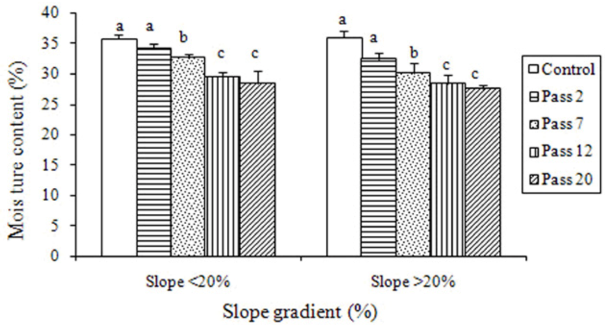

Fig. 8 Effect of traffic levels on soil moisture content at soil depth of 10–20 cm

Soil compaction caused by skidding reduced average moisture content in skid trail. This could be due to forest floor removal and consequences of reduced water infiltration rate. This finding is agreed with the result of Tan et al. (2005). They reported that soil compaction reduced moisture content by 11% after forest floor removal. Carter and Shaw (2002) reported that moisture content decreased with increase in soil bulk density due to decrease in soil porosity and infiltration rate.

Conclusions

The aim of this research was to evaluate the effect of skid trail slope and skidder traffic levels on soil bulk density and moisture content at two soil depths. Results from this study demonstrated that slope steepness had a significant effect on soil compaction and moisture content during skidding operation. Soil bulk density increased and moisture content decreased with increase in traffic levels at soil depths of 0–10 and 10–20 cm. By evaluating the trend of soil compaction we found that skid trail longitudinal slope had maximum soil compaction at lower skidder traffic. As a result, the maximum bulk density occurred at 12 passes, slope <20% and at 7 passes, slope >20%. Since recovery of soil from compaction will take many years, in planning skidding operation we should pay attention to the design of skid trails and limit the longitudinal slope to less than 20%.

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